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50K EXPANDER CYCLE ENGINE DEMONSTRATION

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Abstract

The Air Force Research Laboratory and Pratt & Whitney have teamed to demonstrate an advanced expander cycle engine. Scheduled to be the first of the Integrated High Payoff Rocket Propulsion Technology (IHPRPT) program engine demonstrators, it is scheduled to be tested in late 2000. The expander cycle offers low cost, high thrust to weight and a highly reliable engine ideally suited for upper stages and some future military spaceplane concepts. This technology program will push the performance envelope of existing expanders to higher thrust. Throughout design and manufacture, new methods have been adopted which will increase reliability and reduce component fabrication times.

INTRODUCTION

The Army, Navy, NASA, and Air Force have implemented a three phase, 15 year rocket propulsion technology improvement effort to "double rocket propulsion technology by the year 2010". This initiative, designated the Integrated High Payoff Rocket Propulsion Technology (IHPRPT) established performance, reliability, and cost improvement goals for each of the three phases. These goals are to be met by advancing component technology levels through design, development, and demonstration, followed by an integrated system level demonstrator to validate performance to the IHPRPT system level goals. Pratt & Whitney Space Propulsion Operations, under contract to the United States Air Force Research Laboratory contract is developing a system-level technology demonstrator. This engine, the 50K Expander Cycle Integration ~~and~~ Test, will demonstrate the IHPRPT boost/orbit transfer propulsion area phase 1 goals for an LH_2/LOX upper stage. These system level goals include; a 1% improvement in vacuum specific impulse, a 30% improvement in thrust to weight, a 15% reduction in hardware/support costs, and a 25% improvement in reliability relative to 1993 state-of-the-art levels.

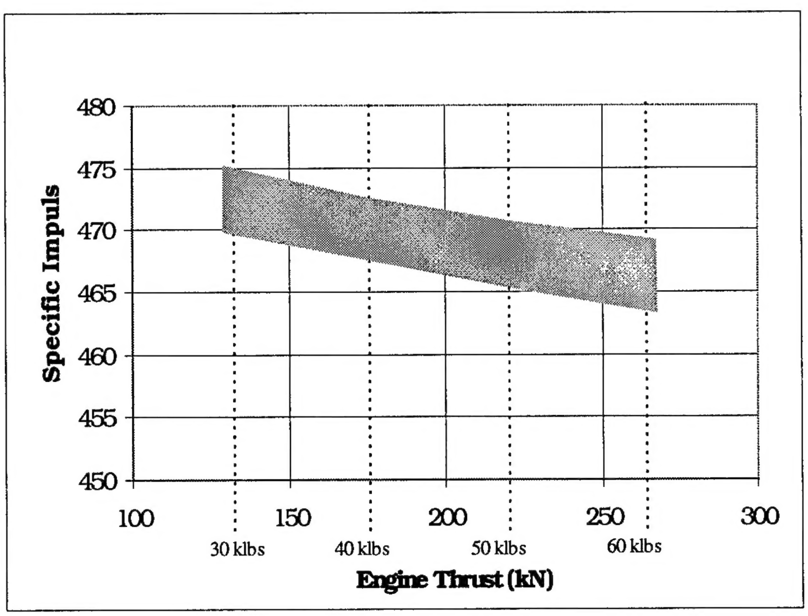


Figure 1 - Range of Upper Stage Engines Derived from 50K Expander Cycle Demo

Technology from this engine will be used in two principle applications—an upper stage upgrade from the current RL10 and a future boost engine for a military spaceplane. Demonstration of the Phase I technology goals will be accomplished by combining contractor IR&D hardware with government funded hardware into a 50klb expander cycle demonstrator engine. Vacuum specific impulse within an acceptable physical envelope is the primary driver for upper stage engine applications. The robustness of the expander cycle is ideal for a military spaceplane since a component failure generally results in a loss of energy to the cycle. A relatively safe shutdown can then be accomplished with simple sensors and control logic, reducing the risk to the vehicle. Generating high sea level thrust is a challenge with current expander cycle chamber pressures. The advanced expander engine, with an approximate 9.48 MPa (1375 psi) chamber pressure, will create a high thrust-to-weight engine for the military spaceplane. Increased heat flux into the chamber coolant per unit hot wall area provides more energy to the turbopump and enables the increased chamber pressure.

CURRENT BASELINE

The only other expander cycle engine in production is the Pratt & Whitney RL10. The RL10 has many variants from the RL10A to the newly created RL10B. It utilizes a two stage turbine driven by the expanded hydrogen from the combuster and nozzle cooling tubes. The RL10 turbine drives both the two stage hydrogen turbopump and the single stage Liquid Oxygen (LOX) turbopump through a gearbox. The range of chamber pressures are from 3.241 MPa (470 PSIA) to 4.137 MPa (600 PSIA). The expander cycle developed for the RL10, shown in Figure 2, is used in each member of the RL10 family, covering the 72600 - 108900 N. (16,500 to 24,750 lb) thrust range with growth potential to approximately 154,000 N (35,000 lbs.). The upper stage production engine derived from the IHPRPT phase 1 demonstrator will allow further growth to 220,000-264,000 N (50,000 - 60,000 lbs.). while maintaining the benefits of the RL10 family history.

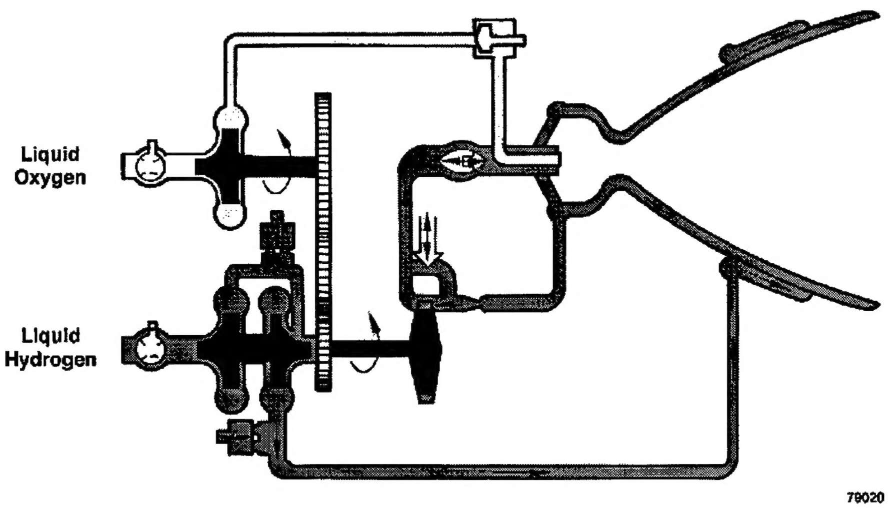
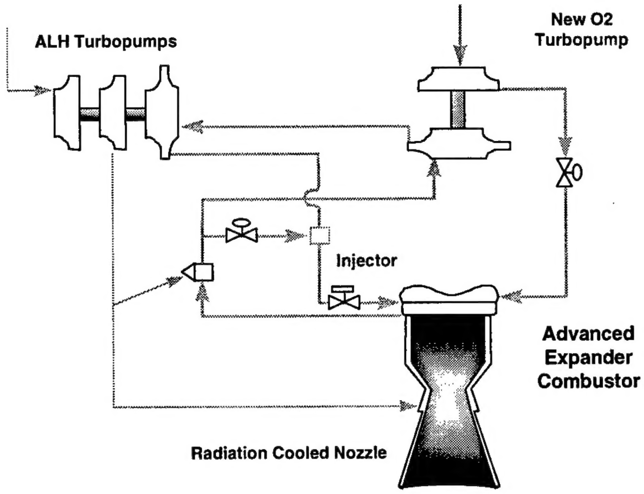
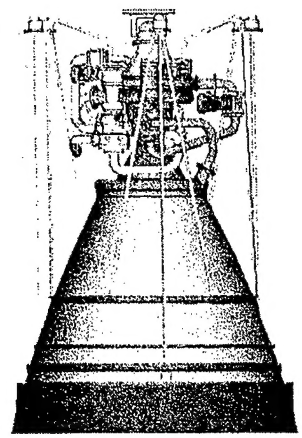


Figure 2 - RL10 Expander Cycle System with Geared LOX Pump

The new advanced engine cycle eliminates the gearbox and drives both turbopumps with expanded hydrogen. The Advanced Expander Combuster (AEC) increased heat load capacity provides increased turbine energy to support an increase in turbopump discharge pressures allowing an increase in chamber pressure. Analysis of an expander cycle with the improved heat load capacity supports a stable expander cycle operating at a chamber pressure of 9.48 MPa (1375 PSIA) with a maximum cycle pressure of 31.7 MPa (4600 PSIA) at the ALH fuel turbopump discharge. The final system balance provided a heat load capacity of 24 MW (22,833 Btu/sec) available to drive both the ALH fuel turbopump and the LOX turbopump with at least 5% margin remaining for roll control thrusters or equivalent bypass requirements.



Advanced Expander Engine Cycle Schematic
Figure 3



Artist Concept of Spaceplane Engine
Figure 4

After the advanced expander engine cycle model (represented by the schematic in Figure 3 and summarized in Table 1) was established, the performance and thermodynamic operating requirements of the individual components were isolated from the system.

Table 1: Demonstration Engine Cycle Summary

Vacuum Thrust, lbf	50,334	Chamber Pressure, psia	1375
Engine Mixture Ratio	6.00	Combustion C* Efficiency	0.99
Chamber Mixture Ratio	6.11	Chamber Coolant Q, Btu/s	22,833
Engine Flowrate, lbm/s	112.0	Chamber Length, in	26.0
Del. Vacuum Isp, sec	450.6	Chamber Contraction Ratio	4.65
Throat Area, in**2	19.09	C*, Char. Velocity, ft/s	7553
Nozzle Efficiency, Cs	0.995	Nozzle AR	64.5
Weight Estimate, lb	715	Nozzle Exit Diameter, in	39.6
Stowed Engine Length, ft	6.7	Roll Control Thrust, lbf	120
Thrust to Weight	70.4	Turbine Bypass, %	5.4

ADVANCED EXPANDER COMBUSTER (AEC)

The primary limiting issue with the expander cycle using today's technology is the amount of heat you can get into the thrust chamber assembly coolant per unit length of thrust chamber assembly. Recent improvements in thermal conductivity material properties has enable the transfer of larger quantities of heat into the expander cycle coolant. The AEC uses advanced copper alloys to provide the heat to support the engine cycle. In doing so higher pump pressures, higher chamber pressures and subsequently higher Isp at reduced weight can be achieved

The AEC design is complete and manufacturing is underway. Individual tubes are being fabricated with a new internal pressurization forming method, which reduces fabrication steps and promises to reduce cost. The structural jacket will be vapor plasma sprayed (VPS) and then strengthened via a Hot Isostatic Press (HIP). Adequate bond

strength between the tubes and the jacket has been demonstrated. A full scale manufacturing test chamber has successfully completed spraying and the deliverable chamber is currently awaiting completion of the tubes.

ADVANCED LIQUID HYDROGEN (ALH) TURBOPUMP

The ALH turbopump was designed to a nominal discharge pressure at a minimum turbopump weight and cost. The combination of high pump discharge pressure and low turbopump weight requires maximum rotor speeds to attain high impeller tip speeds at a minimum impeller diameter. Rotor speed has typically been limited by hydrodynamic and rotordynamic instability using conventional bearing diameter*RPM (DN) limits. The breakthrough design feature of the ALH turbopump is the fluid film rotor support system. The ALH turbopump has been designed with a hybrid hydrodynamic/hydrostatic rotor support system to provide; optimized rotordynamic operation, accurate rotor position control, minimized rotor stresses, bearing loads, and operating clearances. Additionally, the use of fluid film bearings drastically reduces the turbopump part count, directly reducing costs and improving reliability.

The removal of the life-limiting and maintenance intensive current bearing designs such as on the SSME is a critical technology required to achieve safe, reliable, operable, supportable, affordable and long-life hydrogen turbopumps applicable to the next military spaceplane. (Figure 4)

Design of the ALH is complete and fabrication will soon be concluded. The rotor and film bearings have been machined. The turbine housing has been cast and we are awaiting the completion of the pump housing. The pump housing has many complex internal passageways that do not lend themselves to easy castings. The follow-on engineering manufacturing program that will create a flight weight housings will need to examine the casting difficulties encountered here to decrease the casting rejection ratio.

DIGITAL ELECTRONIC ROCKET ENGINE CONTROL (DEREC)

The 50K Expander Cycle Demo will use an "on-engine" digital valve controller DEREC. The DEREC will demonstrate IHPRPT goals and provide assurance of engine health through electronic monitoring and accurate valve control. The proven design of the proposed DEREC will perform timing and sequencing of engine valves to accomplish engine cool-down, pre-start, start, and turbopump throttling and shutdown, while monitoring primary cycle variables to assure system health. The DEREC and electromechanical actuated valves are derivatives of control system components designed by P&W and the Air Force in the Atlas Reliability Enhancement Program (AREP).

CONCLUSION

The IHPRPT 50K Expander Cycle Demonstration will demonstrate new a high conductivity chamber and a fully supported fluid film bearing turbopump. This technology demonstration, schedule for testing in late 2000, will push liquid rocket engine performance to new levels. This technology will provide a highly reliable, low cost upgrade to the existing RL10 upper stages and lead to a robust engine for future military spaceplane applications.